Nuclear Energy University Programs

Nuclear Reactor Technologies FY 2012 Program Needs

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Outline

- Office of Nuclear Reactor Technologies (NE-7)
  - Mission
  - Organization
  - Program Elements

- Overview of each NE-7 Program Area
  - Goals
  - Challenges
  - R&D activities
  - FY 2012 budget

Nuclear Reactor Technologies (NE-7) Overview

- Mission: Develop new and advanced reactor designs and technologies
  - Broaden applicability,
  - Improve competitiveness, and
  - Ensure lasting contribution toward meeting Nation's energy and environmental challenges
- NE- 7 consists of five Offices:
  - NE-71: Advanced Modeling and Simulation – Alex Larzelere
  - NE-72: Light Water Reactor Technologies – R. Smith-Kevern
  - NE-73: Gas Cooled Reactor Technologies – Tom O'Connor
  - NE-74: Advanced Reactor Concepts – Sal Golub
  - NE-75: Space and Defense Power Systems – Owen Lowe
- Research activities are designed to address technical, cost, safety, and security issues associated with various reactor concepts

Nuclear Reactor Technologies (NE-7) Program Elements

- **NE-7 activities primarily fall under two budget elements in FY 2011:**
  - Reactor Concepts Research, Development and Demonstration (RD&D)
  - Nuclear Energy Enabling Technologies (NEET)

- **Reactor Concepts RD&D includes five reactor technology sub-programs:**
  - Light Water Reactor Sustainability Program (LWRS)
  - Next Generation Nuclear Plant Demonstration Project (NGNP)
  - Small Modular Reactors (SMR)
  - Advanced Reactor Concepts (ARC)
  - Space and Defense Power Systems

- **Nuclear Energy Enabling Technologies (NEET) includes four elements:**
  - Crosscutting Technologies
  - Energy Innovation HUB for Modeling & Simulation
  - Transformative Nuclear Energy Concepts (FY 2012)
  - National Science User Facility (FY 2012)

(NEET information will be presented in a separate presentation)

Light Water Reactor Sustainability (LWRS)

LWRS Program Goals

- Develop fundamental scientific basis to allow continued long-term operation of existing LWRs (beyond 60 years) and their long-term economic viability

Benefits

- Current fleet provides >70% of non-greenhouse gas emitting electricity
- Existing reactors reduce burden of new clean electricity that will need to come online

Key R&D areas

- Materials Aging and Degradation
- Risk-Informed Safety Margin Characterization
- Advanced Instrumentation and Controls
- Advanced Fuel Development
- Economics and Efficiency improvements

FY 2012 Budget Request: $21M

LWRS Challenges

- **Extending reactor life to beyond 60 years will likely increase susceptibility and severity of known forms of materials degradation and potentially introduce new forms of degradation**

- **Aging of Structures, Systems and Components (SSC) has potential to:**
  - Increase frequency of initiating events of certain safety transients
  - Create new and more complex transient sequences associated with previously-not-considered SSC failures
  - Increase severity of safety transients due to cascading failures of SSCs

- **R&D needed to provide tools, methods and data for understanding and predicting materials aging and degradation**
  - **Will leverage related modeling and simulation efforts**

LWRS - Advanced Information, Instrumentation and Controls (IIC)

- Current analog technology is not sustainable – need to modernize and improve IIC systems
  - Replacements / upgrades are complex and costly
  - Regulatory uncertainty and a risk-averse industry reinforce the status quo of outdated and antiquated analog I&C
- Digital instrumentation and control technologies will improve plant monitoring and reliability
  - Centralized Online Monitoring (OLM) and Information Integration
  - Improved NDE techniques and sensors to characterize and assess aging and degradation

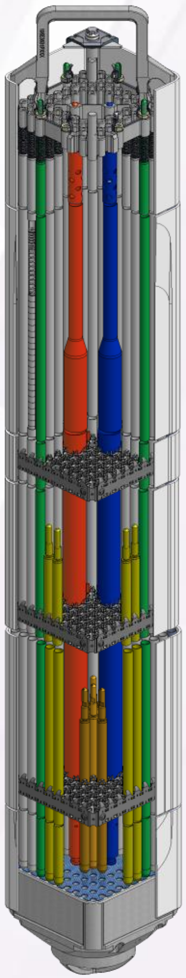
From this…

…to this!

LWRS - Advanced Nuclear Fuels

Goals:

- Improve fundamental scientific understanding and prediction of behavior of nuclear fuel pellets, cladding, and fuel-coolant system
- Establish public-private collaborations to develop and demonstrate advanced fuel types with improved safety margins and improved performance
- Speed implementation of new fuel technologies to industrial application



Planned activities:

- Begin development of new long-life fuel designs with advanced fuel and cladding materials
- Develop predictive tools for advanced nuclear fuel performance
    - e.g., predictive model for fission product release

LWRS - Economics and Efficiency Improvements

- Advanced cooling technologies to minimize water use or environmental impacts
  - Environmental concerns may require modifications to water intakes or cooling tower modifications
  - Water issues can impact siting of new nuclear construction
- Feasibility of expanding the current fleet to non-electric applications
  - Process heat
  - Seawater desalination
- Facilitate additional power uprates

Next Generation Nuclear Plant (NGNP) Demonstration Project

NGNP Program Goals

- **Expand benefits of nuclear power <u>beyond</u> electricity generation through a public-private demonstration project**
  - Work with National Laboratories, industry, Nuclear Regulatory Commission, and international partners to demonstrate high-temperature gas-cooled reactor (HTGR) technology, producing electricity & process heat for industrial applications

Benefits

- HTGRs provide a zero carbon energy source for carbon intensive industrial applications such as petroleum refining and chemical processes
- Increases energy security by reducing the reliance on imported oil

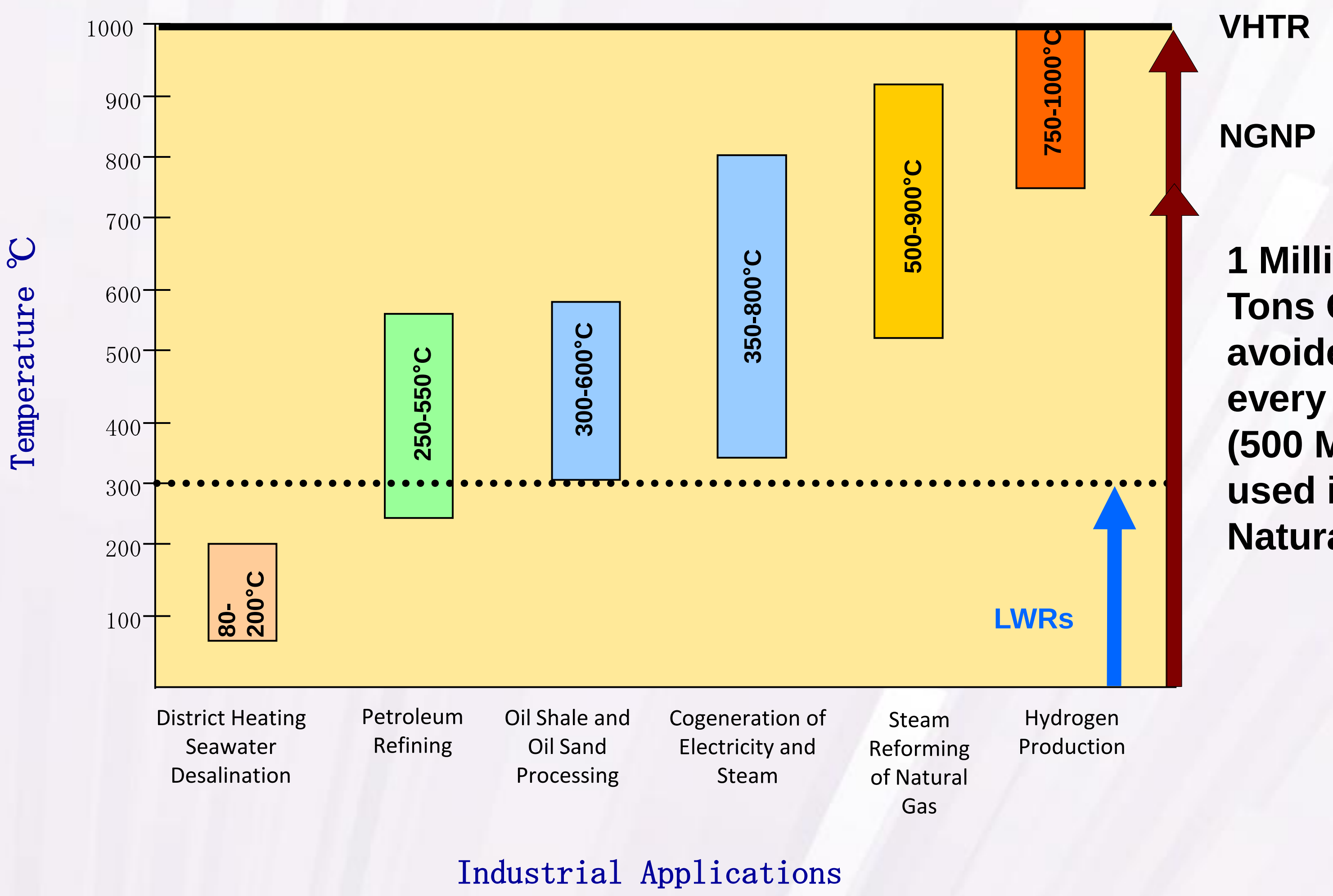
Key R&D areas

- Reactor analysis methods
- Reactor materials
- HTGR fuel development and qualification
- HTGR Heat Transport, Energy Conversion, Hydrogen and Nuclear Heat Applications

FY 2012 Budget Request: $49.5M

- House mark - $63.5 M

NGNP - Potential Contribution of Fission Reactors to Process Heat Industries



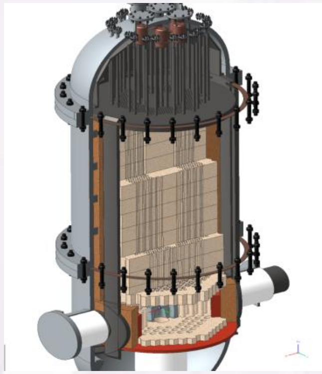
1 Million Metric Tons CO2/year avoided for every HTGR (500 MWth) used in lieu of Natural Gas

NGNP - Analysis Methods R&D

- R&D focused on developing practical tools to analyze neutronics, thermal-hydraulics, and safety
  - Experimental planning and phenomena (Scaling, experimental design, fundamental phenomena identification, costing and PIRT)
  - Modeling and simulation of core phenomena (neutronics, thermal-hydraulics, and multiphysics)
  - Plant simulation and safety analysis, (source term, uncertainty and sensitivity analysis, licensing approaches)

Graphite/Air Reaction Rate Testing

ANL Facility to Validate Reactor Cavity Cooling System Behavior



OSU's High Temperature Test Facility to Model Depressurized Cooldown

INL's Matched Index of Refraction (MIR) Facility to Study 3-D Flow Effects in Plena

NGNP – Materials R&D

- R&D on graphite, ceramics, composites and high temperature structural materials
  - Improved NDE techniques
  - Graphite recycling and long-term oxidation
  - Irradiation damage/high temperature/moisture effects
    - heat exchanger, steam generator, pressure vessel
  - Predicting component lifetimes
  - ASME code development

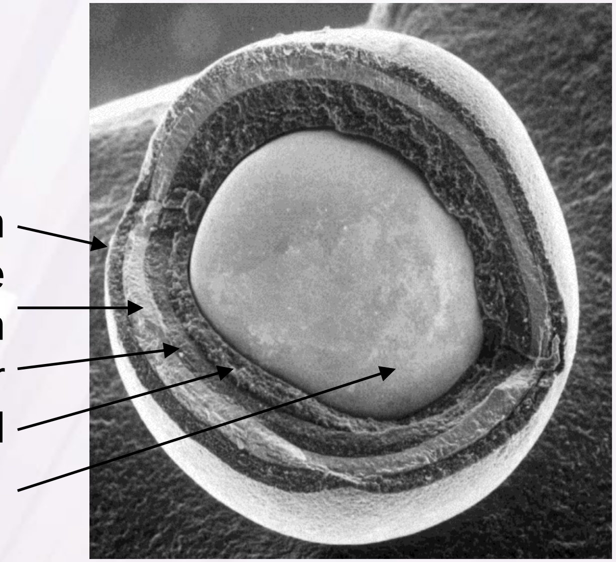
High Temperature Mechanical Testing of Key Alloys

Graphite Characterization Labs at INL and ORNL

NGNP – Fuels R&D

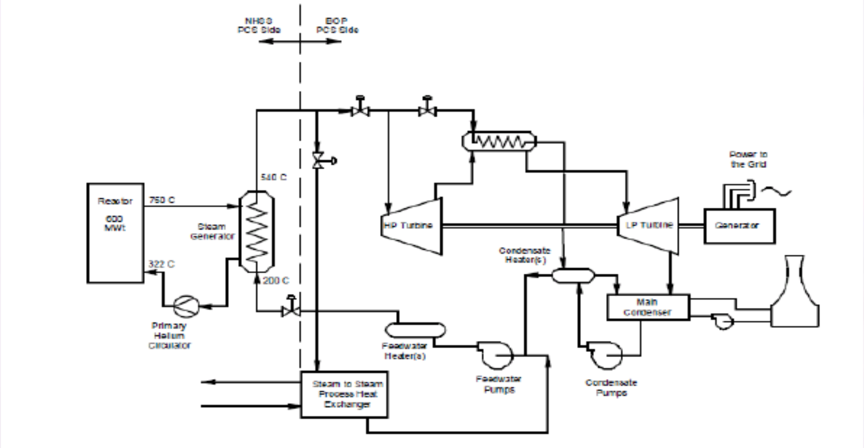
- R&D to design and fabricate high performance fuels with very low failure rates
  - Establish credible fission product transport mechanisms and mechanistic source term under normal, off-normal, and accident conditions
  - Improved quality control techniques for fabrication
  - Develop innovative fuel designs for higher outlet temperatures and increased fuel margins relative to existing concepts

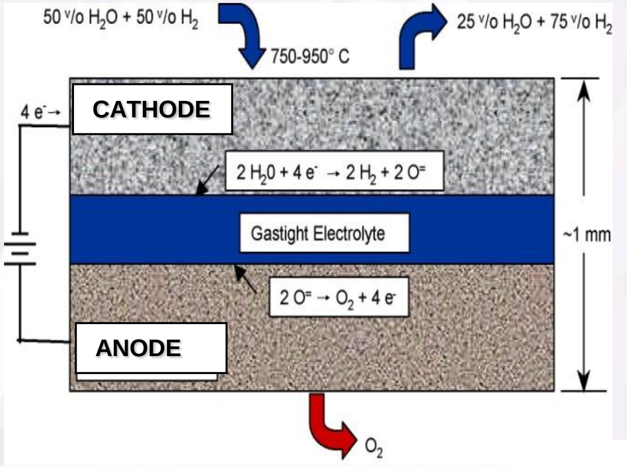
1000 micro coated fuel particle



NGNP- Heat Transport, Energy Conversion, Hydrogen & Nuclear Heat Applications R&D

- Approaches to improve ease of coupling, operability of combined system, and economics
- Modeling of basic energy transfer and conversion
  - load matching and rejection
  - multiple modules
- Development of high temperature steam electrolysis cells for hydrogen production





Small Modular Reactors (SMR)

U.S. Department of Energy

SMR Program Goals

- Facilitate new nuclear power deployment by reducing capital cost and providing more flexible options to owners and investors

Benefits

- Lower initial construction costs
- Inherent/passive safety features
- Increased flexibility
- Opportunity to enhance US technical leadership and global competitiveness

Key activities

- Establish cost-shared projects with industry partners to accelerate design certification
- Develop technologies that further reduce costs
- Develop new tools and techniques to objectively assess SMR safety, performance, and economics
- Develop innovative concepts that utilize advanced technologies to achieve expanded functionality

FY 2011 Budget Request: $28.7M

Small Modular Reactors (SMR)

Challenges:

- Integrated PWR designs introduce new material, inspection, and maintenance challenges
- Performance uncertainty introduced by new designs and technologies
- Departure from traditional licensing experience
- Cost (economies of series versus economies of scale)

R&D focus areas:

- Testing systems to assess PWR concepts with steam generators located within the reactor pressure vessel
- Modeling and simulation of unique SMR characteristics and safety considerations
  - natural circulation, decay heat removal
- Instrumentation and control – measurement , diagnostics, prognostics
- Specialty components, e.g., helical coil steam generators

Advanced Reactor Concepts (ARC)

U.S. Department of Energy

ARC Program Goals

- Reduce long-term technical barriers and uncertainties for advanced technology reactor systems to support future fuel cycle options with improved economics, safety, proliferation resistance, waste management and resource utilization

Benefits

- ARC R&D can lead to innovative reactor concepts that can
  - operate a lifetime without refueling
  - consume existing “waste” and minimize generation of new waste
  - conserve uranium resources

R&D Focus Areas

  - Advanced structural materials and energy conversion
  - Alternative coolant chemistry (e.g., liquid metals and fluoride salts)
  - Advanced systems and components

FY 2012 Budget Request: $21.9M

ARC Key R&D Activities

- **Reactor Concept Development**
  - Evaluate and compare alternative coolants (e.g., liquid metal and fluoride salts) and develop optimal integrated reactor system designs (core, coolants, heat transfer, energy conversion)

- **Reactor Modeling and Simulation and Nuclear Data**
  - Predictive and coupled physics design tools to explore and optimize a broader range of potential concepts and design features
  - Use advanced measurement techniques to obtain key data with unprecedented accuracy and precision

- **Advanced Materials**
  - Advanced structural alloy development and testing
  - Support codification

- **Advanced Energy Conversion Systems**
  - Supercritical CO2 Brayton cycle machinery performance, Computational Fluid Dynamics modeling, corrosion chemistry

Space and Defense Power Systems

Space and Defense Power Systems Program Goals

- Design, develop, build and deliver radioisotope power systems, including radioisotope thermal generators (RTG) for space and terrestrial applications

Benefits

- Enable customer missions in locations and environments where other power systems such as chemical batteries and solar power systems don’t work
- In particular, for NASA, greatly enhance scientific knowledge of the moon, Mars the outer planets beyond

Key R&D areas

- Develop materials for use in the extreme environments of space applications
- Improve the efficiency of thermoelectric couples

FY 2012 Budget Request: $50M

Space and Defense Power System Challenges

Replacement Materials

- Current materials for aeroshell module that protects radioisotope power system fuel during potential atmospheric reentry events perform well but are difficult to manufacture.
- Nation's manufacturing base has moved on. Vendors for currently qualified materials are reluctant to continue limited production.

- **RD&D Goals:**
    - Discover or develop alternate materials. Material will need ablation resistance, thermal conductivity, and structural strength (compressive and tensile) that meet minimum performance requirements.

Space and Defense Power System Challenges

Thermoelectric couples

- Thermoelectric couples that have been used on all radioisotope thermal generators to date have been extremely reliable.
- However they are highly inefficient. Improvements in efficiency have been at best incremental.

- **RD&D goals:**
  - Ultra high efficiency thermoelectric couples--Develop a thermoelectric couple (N and P legs) with hot side temperature of 1000 C. The couple should demonstrate efficiency between 20-30% with stable properties providing for a minimum operable life of 10 years.